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Publication date:
2013

Citation (APA):
Badger, M., Peña, A., Hahmann, A. N., & Hasager, C. B. (2013). *Combining satellite winds and NWP modelling for wind resource mapping offshore*. Poster session presented at ESA Living Planet Symposium, Edinburgh, United Kingdom.

Combining satellite winds and NWP modelling for wind resource mapping offshore

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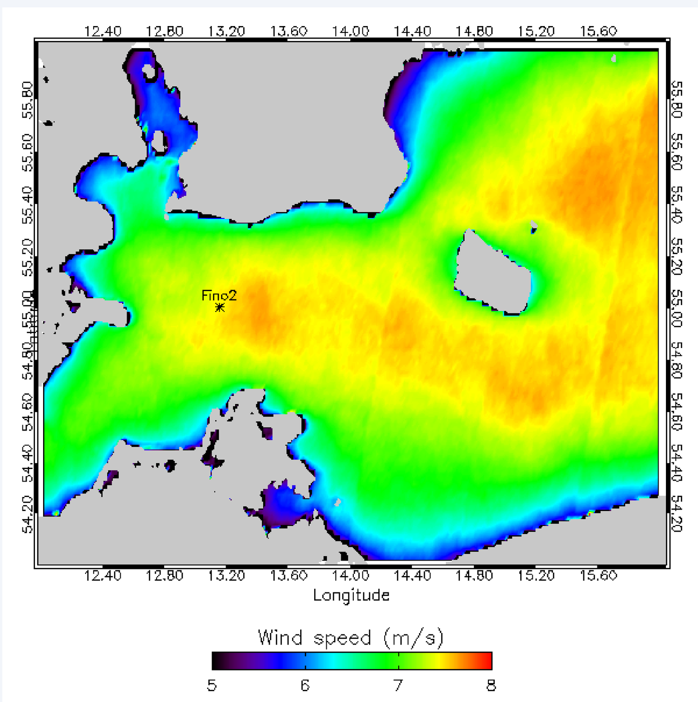
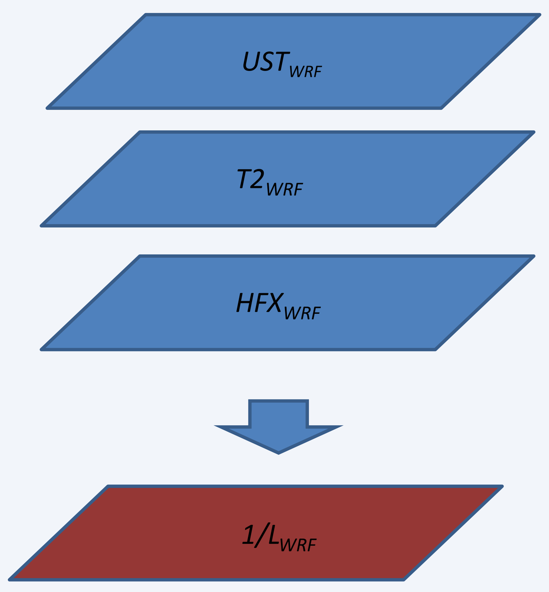
Introduction

Ocean wind fields can be retrieved from satellite-borne active microwave sensors at different temporal and spatial resolutions depending on the sensor type. Processing of both scatterometer and synthetic aperture radar (SAR) observations to wind fields relies on a geophysical model function (GMF), which relates the sea surface backscatter to winds at the standard height 10 m above the sea surface.

For wind energy applications, it is not sufficient to know the 10-m wind conditions because offshore wind turbines operate at heights of 80 m and beyond where the wind power potential is higher. Extrapolation of the satellite wind speed to higher levels requires, among other parameters, information about the thermal stratification (stability) in the atmospheric boundary layer. For the wind direction, turning between the sea surface and higher levels should be considered. A combination of the satellite winds with other data sources is envisioned to account for these effects and to achieve the highest possible accuracy of wind resource maps.



Map of the 10-m mean wind speed retrieved from a series of appr. 1,000 Envisat ASAR WSM scenes.



The data layers from WRF, which are used to calculate the Obhukhov length scale, L, and the mean atmospheric stability correction.

Method

The starting point of our analysis is a map of the 10-m mean wind speed retrieved from appr. 1,000 Envisat ASAR WSM scenes over the Baltic Sea at the resolution 0.02° lat/lon. The winds are retrieved with CMOD5.n, which gives the equivalent neutral surface wind (ENW).

WRF simulations for the same region are available for the period 2006-11. The WRF parameters *UST*, *T2*, and *HFX* are resampled to match the spatial grid of the SAR wind map. The following equations are then applied to calculate the long-term stability correction, $\langle\psi_m\rangle$ and the long-term wind speed at higher levels, $\langle u_z\rangle$:

1) Obukhov length scale: $L = -\frac{UST^3\,T2}{g\,\kappa\,HFX}$ (L>0: stable, L<0:unstable)

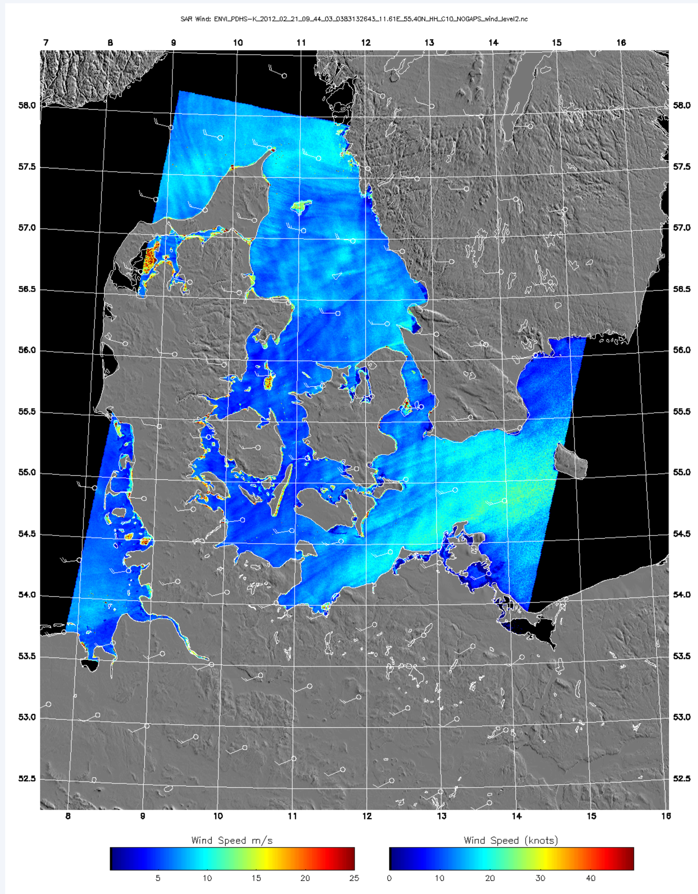
2) Probability density function of 1/L: $P = n_\pm \frac{C_\pm}{\sigma_\pm} \frac{-(C_\pm\,|1/L|\,/\,\sigma_\pm)^{2/3}}{\Gamma[1+3/2]}$

3) Long-term standard deviation: $\sigma_\pm = \frac{g}{\langle T2\rangle} \frac{\sqrt{\langle\left(HFX-\langle HFX_\pm\rangle\right)^2\rangle}}{\langle UST^3\rangle}$

4) Mean stability correction: $\langle\psi_m\rangle = -n_+ \frac{3\sigma_+}{C_+}\, b'z + n_-\, f_-$

5) Mean wind speed at any height: $\langle\frac{\kappa\, u(z)}{u_*}\rangle = \ln\left(\frac{z}{z_0}\right) - \langle\psi_m\rangle$

In the equations, + denotes stable and – unstable conditions. A full description of the equations and their constants can be found in Kelly & Gryning (2010).



Wind field at 10 m retrieved from an Envisat ASAR WSM scene. February 21, 2012 at 09:44 UTC.

Offshore wind turbines at Middelgrunden, Denmark. The turbine hub height is 64 m.

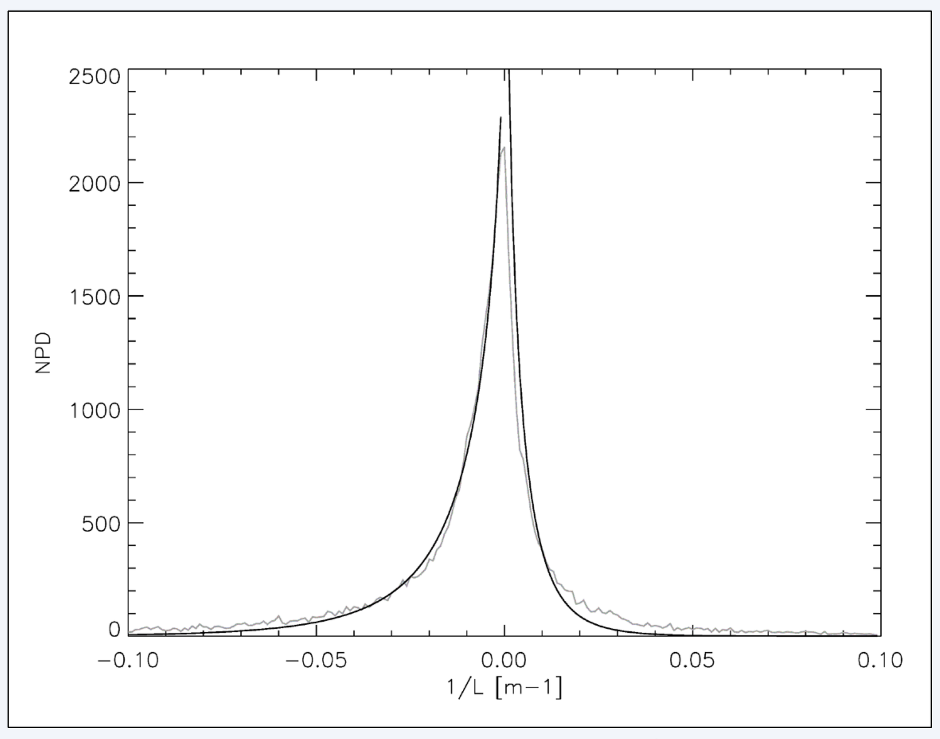
Approach

The problem of vertical wind speed extrapolation is examined by means of satellite winds retrieved from Envisat ASAR and stability information from a Numerical Weather Prediction (NWP) model.

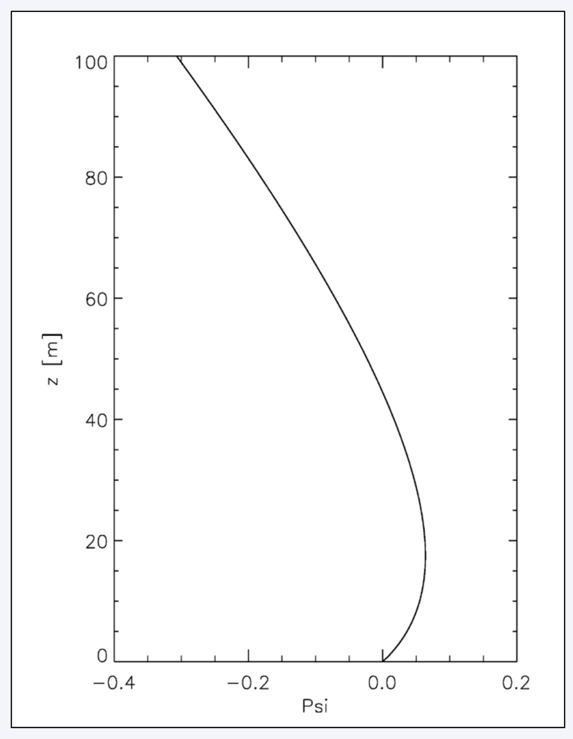
Peña and Hahmann (2012) demonstrated how a long-term stability correction can be calculated from the surface heat flux (*HFX*), the air temperature at 2 m (*T2*) and the friction velocity (*UST*) parameters of the Weather Research and Forecast (WRF) model in very good agreement with long-term sonic-derived observations. It is essential to work with the long-term stability correction for period as opposed to individual samples. Here we follow a similar approach for the wind fields retrieved from SAR.

Results

The following results are found for Fino-2 in the Baltic Sea:



Probability density function of 1/L found from WRF simulations 2006-11 (grey curve). The distribution follows the theoretical distribution (black curves) well.



Long-term stability correction from WRF simulations 2006-11 at different heights.

	SAR	WRF	Mast
$\langle u_*\rangle$	0.26	0.32	-
***U* at 10 m (ENW)**	7.5	8.1	-
***U* at 100 m**	9.0	9.9	10.0

The table shows the mean values of friction velocity $\langle u_*\rangle$ and wind speed U at 10 m and 100 m from three different data sources. The lifted SAR mean winds are lower than the WRF and mast winds at 100 m. This is partly because the initial 10-m winds from SAR are also lower than the WRF winds.

References

Peña, A. & Hahmann, A.H. (2012). Atmospheric stability and turbulent fluxes at Horns Rev – an intercomparison of sonic, bulk and WRF model data, *Wind Energy*, 15 (5), 717-731.

Kelly, M. & Gryning, S.-E. (2010). Long-Term Mean Wind Profiles Based on Similarity Theory, Boundary-Layer Meteorology, 136 (3), 377-390.

living planet symposium 9–13 September 2013 | Edinburgh, UK

Acknowledgements

Satellite data from the European Space Agency.

Funding from the EU-projects NORSEWInD and EERA-DTOC.

The Johns Hopkins University, Applied Physics Laboratory is thanked for the APL/NOAA SAR Wind Retrieval System (ANSWRS) and software support.